Stratified Flow, Wave Packet Reflection and Topographic Currents

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LONG-TERM GOAL

Our basic aim is to achieve a better understanding of the turbulent flow of the oceans in terms of the laws that govern the behavior of vortices and waves and their interactions.

OBJECTIVES

In our internal-wave project, we are using numerical simulations to study the dynamical evolution of internal wave packets. We plan to study in detail the process of reflection of a packet from regions of weak density gradient. Packets propagating away from the thermocline may be reflected back toward the thermocline. In the process of reflection, high amplitude packets may break causing mixing. This would tend to erode the boundaries of the thermocline.

In our topographic work, we wish to understand the role that bottom topography plays in permitting or inhibiting the bifurcations of coastal currents. We are investigating the role of topography in establishing the circulation in the Adriatic. In particular we want to understand the circulation above the Mid and South Adriatic Pits.

APPROACH

In our topographic investigations, we are comparing the results from quasi-geostrophic model simulations for specific processes with results from a 30 layer DieCast model of the Adriatic. To answer basic questions about the relative importance of fluctuations in wind forcing and topographic effects, we are embarking on a series of simulations in which not only the winds, but also the topography will be modified.

WORK COMPLETED

For our stratified flow work, we have completed studies on both the continually forced flow at the 20 m vertical scale and the propagation of a wavepacket of the type described above. This work is detailed in Carnevale, Briscolini and Orlandi (2001), Carnevale and Orlandi (2000) and Carnevale, Briscolini, Orlandi and Kloosterziel (2001). To better understand the mixing resulting from the breaking of internal waves, we have investigated the Rayleigh-Taylor instability. An article on this has been published in JFM (Carnevale, Orlandi, Zhou and Kloosterziel, 2002) and another has been accepted for publication in JFM (Kloosterziel and Carnevale, 2002). In connection with our earlier quasi-

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14. ABSTRACT
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15. SUBJECT TERMS

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geostrophic models, a question arose about the validity of various boundary conditions, and we have investigated this further in the context of oceanic circulation. This study is reported in Carnevale, Cavallini and Crisciani (2001).

For our Adriatic Sea studies, with the collaboration of D. Dietrich and P. Orlandi, we have made a very accurate circulation model based on the DieCast code. Once we were convinced that the model faithfully reproduces temperature and circulation patters in the Adriatic over a seven-year simulation, we began a series of comparison runs with different topographies to assess the importance of various topographic features on the circulation. A report on this latter work is being prepared for inclusion in the proceedings of the Center for Turbulence Research, Stanford University.

RESULTS

We examined the propagation of a low amplitude packet trying to exit the thermocline. We found that such a packet can be reflected from a region of weak stratification without losing coherence, although dispersion causes significant broadening of the packet. Breaking of strong packets on reflection will erode the density gradient further. We have performed two and three dimensional simulations to investigate these matters. Through three-dimensional simulations, we have demonstrated that rotation can suppress the formation of the turbulent mixing zone (TMZ) that results from the Rayleigh-Taylor instability, and we have analyzed this result in terms of the vortex ring structure within the bubbles that drive the development of the TMZ.

One aspect of our Adriatic Sea studies was to test the influence of the presence of the Jabuka Pit, also called the Pomo or Mid Adriatic Pit (MAP), on the circulation. In figure 1. we show two of the model topographies that were used in this study. The one on the left is a 2.5 min resolution version of the actual Adriatic bottom topography. This shows the important South Adriatic Pit and MAP. The DieCast model uses step-like topography; the levels for some of these steps are indicated in meters. The present study focused on the importance of the steep northern slope of the MAP seen near the middle of the Adriatic in this figure. In the model topography on the right, the MAP has been replaced by a constant slope. The surface flow of the Adriatic often has a strong current flowing along the direction of the northern flank of the MAP. Both topographic effects and wind forcing have been considered possible sources for this flow. By simulating two year-long runs with the same winds but different topographies, we can get an idea of the influence of the topography in creating this current. In figure 2, we show the cross-Adriatic velocity, that is the velocity in the northeast direction, averaged over the year. In the figure on the left, from the run with the 'real' topography, there is a strong mean flow along the northern flank of the MAP that crosses the Adriatic from Croatia to Italy, while in the figure on the right, from the run with no MAP, there is no such current. This demonstrates the ability of this topographic feature to generate such a strong current.

IMPACT/APPLICATION

It is often rather difficult to reconstruct the flow structures in a given volume of ocean from available observational data. Various explanations may be offered to explain a particular overturning event seen in a density profile. By simulating flows that produce similar structures in a three dimensional data set, we hope to be able to decide on the validity of various hypotheses that may be used to explain the occurrence of such structures. We have found strong mixing events in regions of high strain and steep isopycnal slope, and these may be related to the overturning events observed by Alford and Pinkel (2000). We shall study how these events can be triggered by the passage of a strong wavepacket as

suggested by Alford and Pinkel. Our results on the Rayleigh-Taylor instability may help us better understand mixing resulting from overturning of internal waves.

Our results on flow over topography may be useful in analyzing the flow in a variety of places where strong topographic variations occur in the along-shore direction. In particular, the flow along the steep side of the Jabuka pit in the Adriatic seems to be a good example of the flow we may be able to predict analytically. We have compared the trajectories of drifter tracks (Poullain, 1997) and found that many line up with the steep gradient of the northwestern edge of the pit indicating a current, very much as our results predicted.

RELATED PROJECTS

In addition to our work discussed above, we completed a study on the effect of thermal perturbation on trailing vortices behind aircraft (Orlandi, Carnevale, Lele and Shariff, 2000). We are also collaborating with R. Kloosterziel (U. Hawaii) on the stability of vortices in stratified flow and on internal wave packet propagation.

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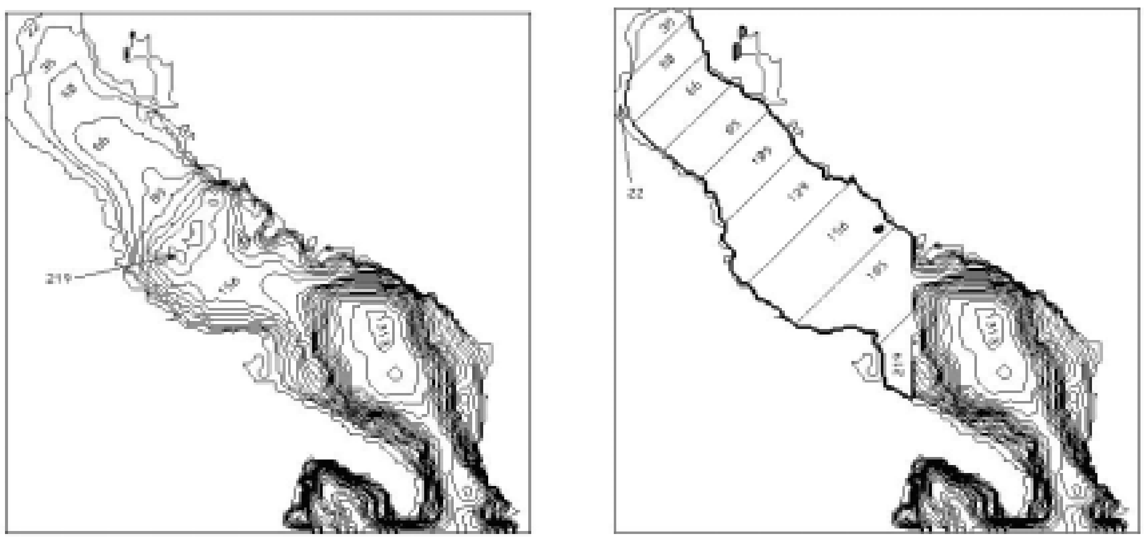

Figure 1. Contours of topography for two models of the Adriatic Sea. The left panel shows a 2.5 min resolution version of the actual bathymetry. Note there are two depressions, the Mid and South Adriatic Pits. The numbers indicate the depth in meters for select steps in our adaptation of the DieCast model to the Adriatic. The figure on the right shows our model topography for the simulation without the Mid Adriatic Pit.

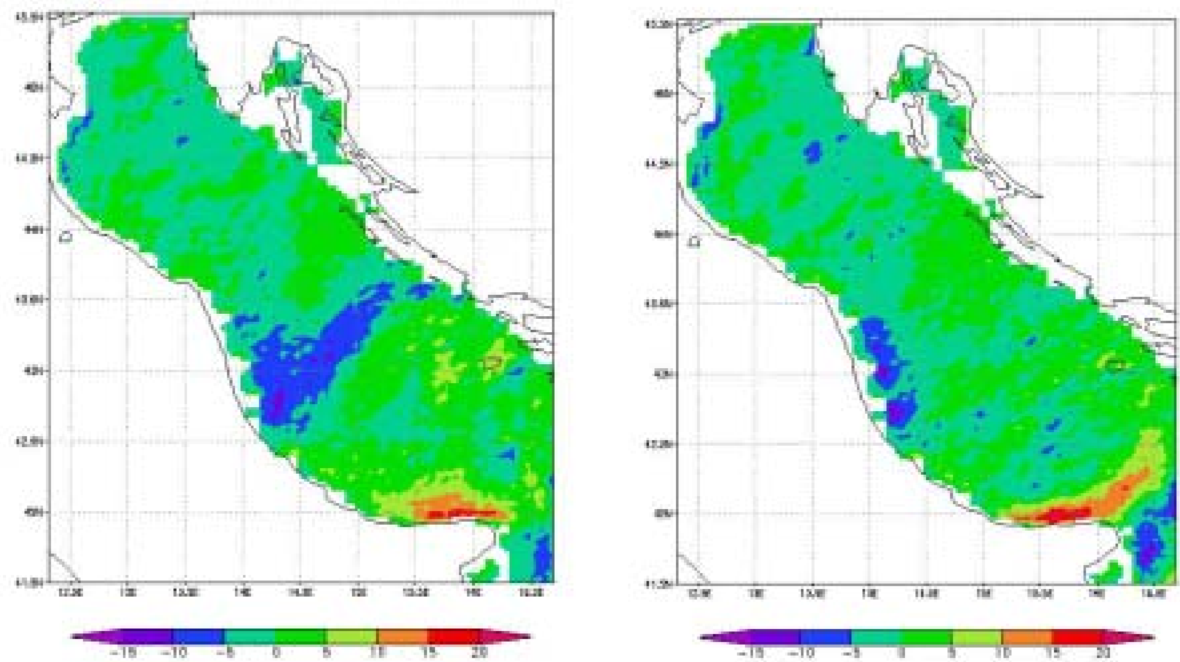

Figure 2. Contour plots of the northeastward component of velocity. This direction was chosen because it is nearly aligned with the orientation of the Mid Adriatic Pit. The fields shown are year-long averages taken from the simulations of flow over the two topographies shown in figure 1. Note the strong cross-Adriatic flow over the Mid Adriatic Pit in the left panel that is absent in the right panel.